METHANE de-NOX® for Utility PC Boilers

Quarterly Technical Progress Report
for the period ending December 31, 2004

Covering Period: October 1 – December 31, 2004

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Date of Report: January 28, 2005

Award Number: DE-FC26-00NT40752

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All-Russian Thermal Engineering Institute (VTI)

DISCLAIMER

ABSTRACT

Preparations for conducting large-scale combustion tests with caking bituminous coal continued during the start of this quarter. Major project accomplishments related to bituminous coal testing included: a CFD preheat model and evaluation, an update of the process flow diagram and a detailed preheat burner mechanical design (suitable for construction) for firing bituminous coal. Installation and testing of the 85 MMBtu/h bituminous coal preheating system was planned to take place before the end of December. Based on the inability to conduct testing in Riley's Commercial Burner Test Facility (CBTF) during freezing weather, a schedule review indicated required site work for testing bituminous coal at the CBTF could not be completed before freezing weather set in at the site. Further bituminous preheat modification work was put on hold and efforts turned to securing the test facility over the winter season. Bituminous coal tests are therefore delayed; April-May 2005 is earliest estimate of when testing can resume. A request for a time extension was submitted to DOE to extend the project through September 2005 to allow time to secure additional funding and complete the bituminous coal testing. Removal of the PRB PC Preheater from the CBTF burner deck was completed. Decommissioning of the CBTF for the winter was also completed.

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EXECUTIVE SUMMARY

Project Objectives: The overall project objective is the development and validation of an innovative combustion system, based on a novel coal preheating concept prior to combustion, that can reduce NO_x emissions to 0.15 lb/million Btu or less on utility pulverized coal (PC) boilers. This NO_x reduction should be achieved without loss of boiler efficiency or operating stability, and at more than 25% lower levelized cost than state-of-the-art SCR technology. A further objective is to ready technology for full-scale commercial deployment to meet the market demand for NO_x reduction technologies resulting from the EPA's NO_x SIP call.

Background: A novel pulverized coal-preheating approach for NO_x reduction was developed by the All Russian Thermal Engineering Institute (VTI) for use on PC utility boilers. The approach consists of a burner modification that preheats pulverized coal to elevated temperatures (up to 1500°F) prior to coal combustion. This releases coal volatiles, including fuel-bound nitrogen compounds, into a reducing environment, which converts the coal-derived nitrogen compounds to molecular N_2. The quantity of natural gas fuel required for PC preheating is in the range of 3 to 5% of the total burner heat input. Basic combustion research and development of the preheat PC burner was conducted by VTI in the early 1980's. Following these promising laboratory results, commercial-scale PC preheating burners of 30 and 60 MW_t capacity were developed and demonstrated in field tests conducted in several Russian power stations.

The advanced PC preheating combustion system being developed in this project for direct-fired PC boilers combines the modified VTI preheat burner approach with elements of IGT's successful METHANE de-NOX technology for NO_x reduction in stoker boilers. The new PC preheating system combines several NO_x reduction strategies into an integrated system, including a novel PC burner design using natural gas-fired coal preheating, and internal and external combustion staging in the primary and secondary combustion zones.

Design, installation, shakedown and initial PRB coal testing of a 3-million Btu/h pilot system at RPI's Pilot-Scale Combustion Facility (PSCF) in Worcester, MA demonstrated that the PC Preheat process has a significant effect on final NO_x formation in the coal burner. Modifications to both the pilot system gas-fired combustor and the PC burner led to NO_x reduction with PRB coal to levels below 100 ppmv with CO in the range of 35-112 ppmv without any furnace air staging. Pilot testing with PRB coal is complete.

Initial pilot testing with caking coal resulted in deposition and plugging by caked material inside of the gas combustor. A series of modifications to the combustor configuration and operation have been developed and tested during previous quarters, and testing of several more versions was continued in the current quarter. One of these approaches using a stainless steel liner indirectly cooled with air was successful in sustaining operation with caking coal up to 150 lb/h.

Installation and shakedown testing with natural gas and PRB coal was completed for the large-scale prototype coal preheater. Large-scale testing with PRB coal was discontinued due to the inability of the coal mill to meet the 85 MMBtu/h design firing rate. The project was therefore redirected toward design, installation and testing of the 85-million Btu/h preheater for bituminous coal. Based on extensive pilot-scale testing completed earlier in the project, 2-D modeling and design activities were then completed based on the use of staged, annular protective air films to control temperature and prevent deposition on the preheater walls. The preheater mechanical design was finalized and a preliminary bill of materials specified. Modifications to Riley's CBTF for testing a bituminous feedstock were summarized and additional CFD models were conducted which evaluated the effect of varying the distribution of natural gas injection in the preheater. Based on schedule concerns and weather constraints, a decision was made to delay bituminous coal tests and decommission the test facility for the winter. Decommissioning tasks included draining the furnace water jacket, ash removal and securing the protection of test hardware. Earliest estimate for resumption of preheat tests with bituminous coal are in April or May of 2005.

EXPERIMENTAL

Pilot Unit

Fabrication, installation and initial testing of the pilot-scale coal preheating system were completed in the fall of 2001. The unit is sized for operation with natural gas and pulverized coal at a total firing rate of approximately 3-million Btu/h and includes all equipment and controls necessary to operate and monitor energy and environmental performance of the system. A gravimetric feeder is used to regulate pulverized coal flow through a rotary airlock into a natural gas-fired preheater combustor. The combustor produces hot combustion gases, which combine with the pulverized coal to produce a mixture of coal char and pyrolysis products at the desired test temperature.

In the original pilot system configuration, the combustor centerline was vertical and two pipe sections after the combustor provided additional residence time for the coal at the preheated conditions prior to entering the PC burner. However, pilot testing experience together with commercial design guidance from RPI redirected the development of both the pilot and commercial units toward a horizontal combustor design with no diameter change between the combustor and burner. The preheater combustor was therefore relocated to a horizontal configuration with the combustor exit coupled directly to the PC burner inlet, eliminating the two pipe sections.

In the modified pilot unit, the velocity of the devolatilization products in the combustor and burner is increased over previous pilot testing to minimize separation and impingement of coal on inner surfaces prior to reaching the burner face. The higher velocities are more consistent with standard design criteria developed by RPI for their commercial CCV burners. The higher combustor velocities were achieved by inserting a liner in the combustor to reduce its internal diameter. The liner also facilitates testing of various designs and operating approaches to eliminate plugging of the combustor with caking coals. Various liner materials, including metal and ceramic, and liner cooling methods are being developed and tested to determine their effect on wall deposition and plugging.

During testing, real time operating data are collected at 1-second intervals and recorded by the personal computer-based data acquisition system (DAS). The concentrations of CO, CO_2, O_2, THC and NO/NO_x in the pilot unit exhaust and the furnace exit are continuously monitored by on-line gas analyzers, including a Rosemount Analytical Model 880A infrared CO analyzer, a Rosemount Analytical Model 880A infrared CO_2 analyzer, a Rosemount Model 400 flame ionization total hydrocarbons (THC) analyzer, a Rosemount Analytical Model 755R paramagnetic O_2 analyzer, and a ThermoElectron Model 14A chemiluminescence NO_x analyzer.

The preheater gas combustor temperatures are monitored by thermocouples installed on both the outer walls and inside of the combustion chamber. Temperature of the gas/air mixture is monitored in the gas/air plenum entering the combustor nozzles.

Large-Scale Prototype Unit

The CBTF comprises a large horizontally fired dry bottom furnace capable of testing full-scale burner systems with firing capacities up to 100 MMBtu/h. The furnace is fully integrated with coal storage, grinding and feeding, emissions control, and continuous flue gas sampling and analytical subsystems.

Coal is pulverized and dried in a DB Riley Model 350 Atrita pulverizer, which is fed from a 40-ton bunker by a weigh-belt feeder and rotary valve. The mill's air supply system includes a Venturi air flow meter, fan and natural gas direct-fired heater to supply a measured amount of hot air to the pulverizer to dry and transport the coal. The CBTF is capable of firing in both the direct fire mode and from an intermediate storage bin (indirect fire). All testing will be conducted in the direct fire mode to simulate the most common firing method in the U.S market. Drying and transport air will be separated from coal stream immediately ahead of the preheater combustor inlet. The separated air will be directed to one of the three air channels in the coal burner. Secondary air will be preheated to 600 ºF by a separate fan and heater and routed to the coal burner. Air can be routed to the burner through an integral windbox plenum or through separate external ducts. Flow to each burner air channel can be regulated independently. Ports are also available at several locations for furnace air staging.

Flue gas composition will be monitored continuously. A multiple-probe sampling grid consisting of sintered Hasteloy filters is mounted in the CBTF exit duct, just upstream of the flue gas scrubber. The in-duct filters remove the majority of particulate, and the flue gas is drawn through stainless steel tubing, ice-bath conditioners, and a final filter by individual sample pumps. A rotameter at the outlet of each pump is used to admit equal flow of clean, dry sample from each grid probe to a manifold. The proper flow of sample for each continuous analyzer is supplied from the manifold.

Continuous monitors are used to measure O_2, CO_2, CO, NO/NO_x and SO_2. In addition to the gas sampling grid, a separate water-cooled probe is used to withdraw particulate samples at the CBTF outlet for determination of carbon burnout. A high velocity thermocouple probe monitors furnace outlet temperature.

The CBTF is fully instrumented to allow continuous measurement and recording or all relevant flow, pressure and temperature readings to allow complete material and energy balances to be developed for each testing period.

RESULTS AND DISCUSSION

Project Status:

Task 1.1 Pilot-Scale Design

No work was performed on this task during the reporting period.

Task 1.2 CFD Modeling

Pilot Unit

No work was performed on this task during the reporting period.

Large-Scale Prototype Unit

A total of nine 3-D modeling cases were completed for the modified preheater for bituminous coal. The goals of 3-D modeling effort were: 1) evaluate effect of gravity and required injection characteristics to avoid coal deposition on the preheater floor; 2) evaluate two injection approaches for the protective air, and optimal distance of the injection ports to the preheater wall; 3) evaluate angular uniformity of the thermal data for preheater walls obtained from 2-D modeling. 3-D CFD model was developed for the preheater and total of nine 3-D cases were parametrically modeled with variable geometry and flow rates of the injected streams. Varied geometry of the preheater included the following: lengths of three individual sections of the preheater; diameters of the individual sections of the preheater; preheater throat diameter; shape of the injection ports for the protective air; removed Venturi section in the preheater. Varied operational parameters were natural gas firing rate; auxiliary natural gas for axial injection firing rate; main combustion air flow; air flow for auxiliary natural gas; and air flow distribution between protective air injection sections. Results of 3-D modeling confirmed the data derived from the 2-D modeling effort and specified the sizing of the preheater and air /gas flow distributions. Details of the modeled cases are presented below. A process diagram for the new preheater configuration is shown in Figure 1. The yellow arrows in Figure 1 represent the velocity vectors for the annular gas burners and red arrows for the coal pipe gas burner. The arrow colors correspond to the magnitude of the velocity for each stream.

Figure 2 shows the internal temperature profiles inside the preheater in dual-firing configuration together with the corresponding wall temperatures along the preheater's length. The average wall temperature of the preheater is 1650 °F. However, due to injection of the protective air at locations air2 and air3 through individual nozzles, the flow stagnant area between the nozzles can become a flame holder which would result in rise of local peak temperature to 2000°F.

Figure 3 shows the relative intensity of collisions of coal particles with the preheater walls. The amount of collisions is negligibly small with exception of the 4-inch long zone at the preheater exit. The results of CFD analysis show that the firing rate of auxiliary natural gas can be used to control intensity of particles impingement on the reactor walls. The reduction of the auxiliary NG flow produces narrower coal stream and lowers average coal preheat temperature, while an increase in auxiliary NG firing rate tends to expand coal stream and increase the average preheat temperature. Therefore, this control mechanism could be used to additionally control plugging together with the main control mechanism though us of protective air.

Figure 4 shows predicted particle tracks in the preheater colored by particle residence time in the preheater. Note that impingement of particles is minimal in this case, with the exception of a small particle recirculation zone around air3 injection nozzles. It is expected that this zone can be minimized by further adjustment of the annular nozzle injection scheme and air 3 flow rate.

In the result of 3-D modeling, 2-D results were confirmed and the optimal design configuration for the preheater was defined. The data on the sizing of the preheater, required flow rates, and thermal profiles were used for the engineering design.

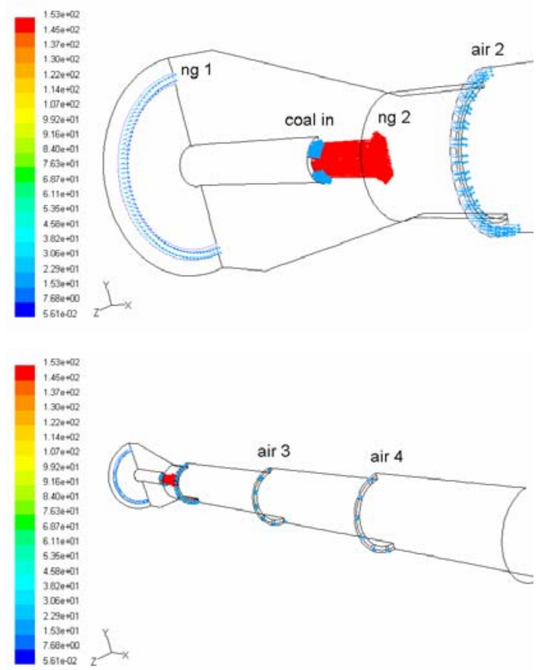

Figure 1. Process schematic for the bituminous coal preheater

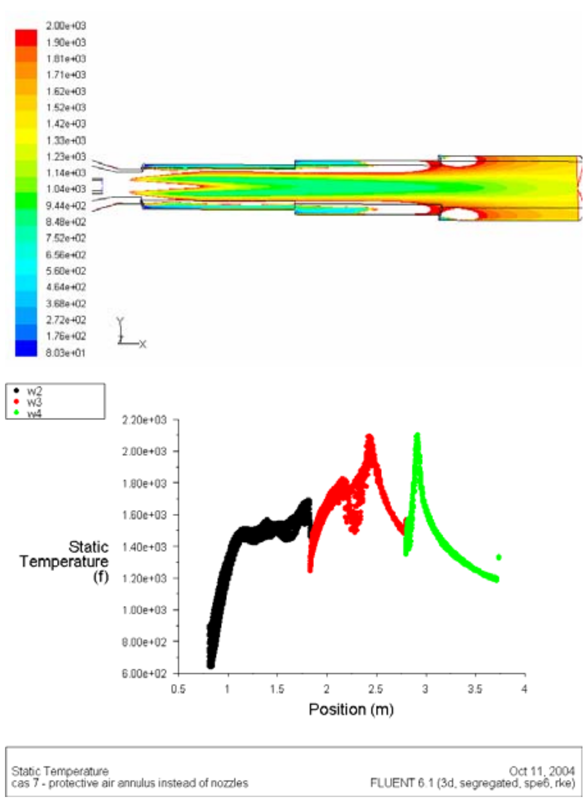

Figure 2. Preheater internal temperature contours (top) and corresponding wall temperatures (bottom

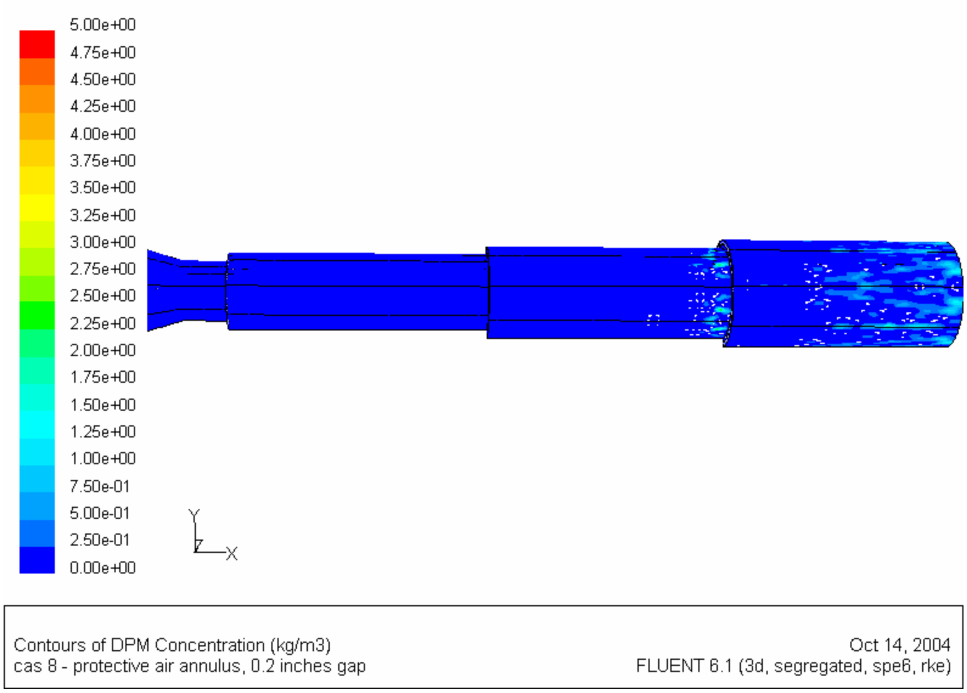

Figure 3. Amount of particle collisions with the wall in arbitrary units

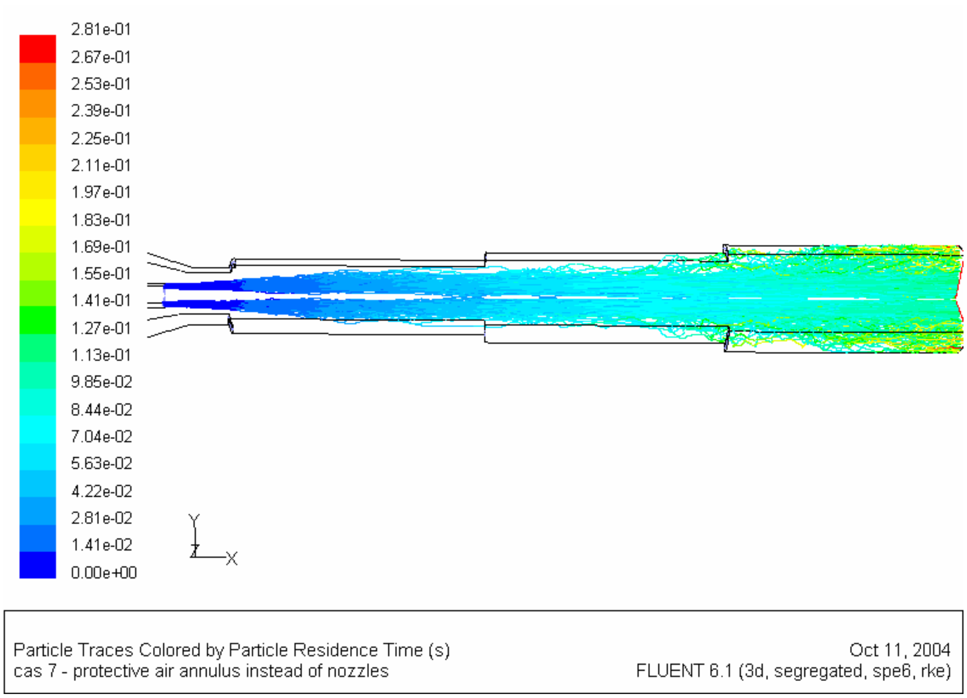

Figure 4. Particle tracks colored by particle residence time in the preheater

Task 1.3 Pilot-Scale Equipment Fabrication and Installation

No work was performed on this task during the reporting period.

Task 1.4 Pilot-Scale Testing

No work was performed on this task during the reporting period.

Task 1.5 Pilot-Scale Data Evaluation

No work was performed on this task during the reporting period.

Task 2.1 Commercial Prototype Engineering Design

A search of coal suppliers was conducted and a bituminous coal suitable for test work was located. This coal matched the coal specification developed last month and has a high volatile content, 34% as-received.

A preliminary detailed mechanical design for a bituminous coal preheater was completed this period. Design guidance was provided by GTI through its CFD modeling results. Design details such as final dimensions, materials of construction, stress analysis and thermal growth issues were worked out with assistance from Riley engineers and designers. This bituminous burner incorporates a concentric multi-barrel preheat coal pipe concept which provides an air layer or film along the inside diameter of the different barrel sections of the burner coal pipe, see Figure 5. This air film provides cooling and an oxidizing zone to prevent deposit formation on the inner metal surfaces of the barrels. Deposition on the inside radius of the coal pipe was recognized as the major problem in pilot-scale efforts while firing a bituminous coal. Barrels are constructed with Rolled Alloys, RA330, material which is suitable for operating temperatures up to 2,000 °F. Other metals such as RA253MA or RA 353MA are acceptable substitutes depending on cost and availability. Plans also call for using the same gas preheat burner as installed in the PRB preheat combustor to speed the assembly construction.

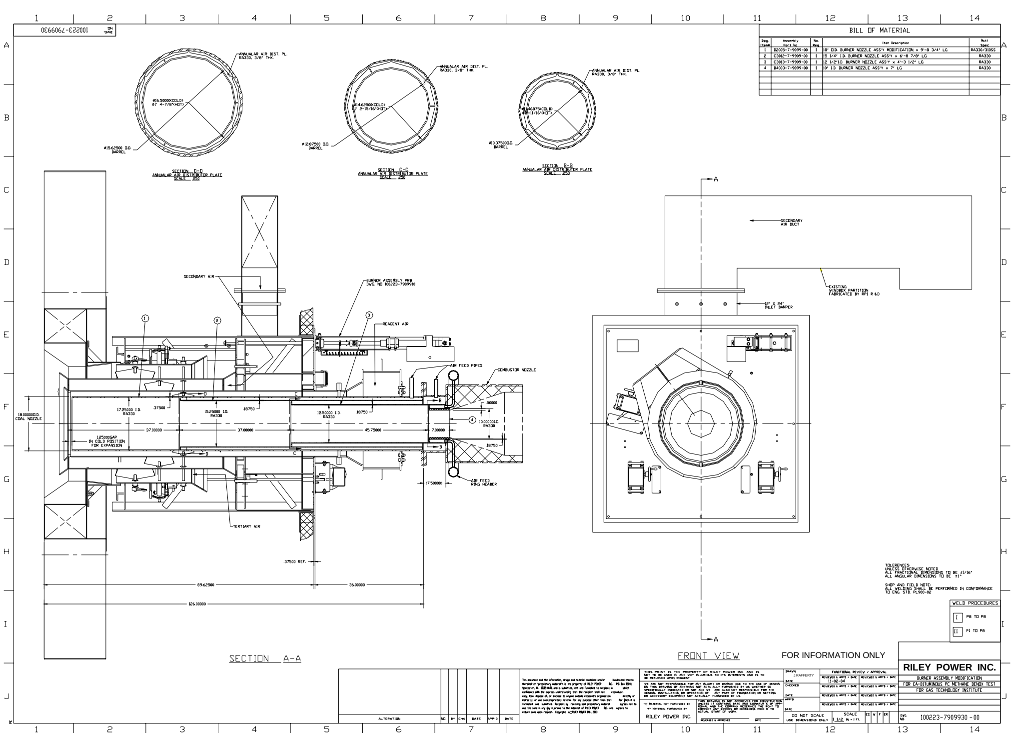

Figure 5. Bituminous Coal Preheat Combustor Design

This final design of the bituminous coal preheat combustor compared with the PRB arrangement is more compact, its approximately 10 ft less in overall length as compared to the PRB preheater.

Task 2.2 Baseline Data Review

No work was performed on this task during the reporting period.

Task 2.3 Commercial Prototype Construction

No work was performed on this task during the reporting period.

Task 2.4 Commercial Prototype Testing

No work was performed on this task during the reporting period.

Task 2.5 Data Processing and Evaluation

Not work was performed on this task during the reporting period.

Task 2.6 Commercialization Plan Development

This task has been deleted from the project workscope.

Task 2.7 Design and Fabrication of Commercial Burner System

This task has been deleted from the project workscope.

Tasks 1.6 & 2.8 Management and Reporting

It was determined that insufficient time and funding was available to complete design, installation and testing of the 85 MMBtu/h bituminous coal preheating system before the end of December. The primary schedule constraint is the inability to conduct testing in the CBTF during freezing weather, which generally corresponds to the period between the end of December and the end of March. A request for a time extension was submitted to DOE to extend the project through September 2005 to allow time to secure additional funding and complete the bituminous coal testing. Removal of the PRB PC Preheater from the CBTF burner deck was completed. Decommissioning of the CBTF for the winter was also completed.

Plans for Next Quarter:

- Continue securing additional funding from cost share sources sufficient to complete the remaining work scope.
- Complete design and modification of the large-scale test unit for bituminous coal

CONCLUSIONS

The project has been redirected toward design, installation and testing of the 85-million Btu/h preheater for bituminous coal. Project activities at the CBTF site have been placed on hold pending approval of a time extension for the project and securing of additional funds to complete the large-scale bituminous coal testing and development work.

REFERENCES

N/A

Milestone Status Table: The proposed revised completion dates for all project tasks and major milestones are shown below.

ID No.	Task / Milestone Description	Planned Completion	Actual Completion	Comments
♦	Kickoff Meeting	5/2/2000	5/2/2000	Complete
1.0	Technology Development			
1.1	Pilot-Scale Design	8/31/2000	12/31/2000	Complete
1.2	CFD Modeling-Pilot and Commercial Scale	6/30/2001		Pilot-scale modeling complete
1.3	Pilot-Scale Equipment Fabrication and Installation	11/30/2000	9/30/2001	Pilot Scale complete
1.4	Pilot-Scale Testing – Caking Coal	6/15/2004		Hold
1.5	Pilot-Scale Data Evaluation – Caking Coal	6/15/2004		Hold
1.6	Task 1 Management and Reporting	7/15/2004		
♦	Task 1 Report	8/15/2004		Hold
2.0	Technology Validation			
2.1a	Commercial Prototype Engineering Design - PRB Coal	4/15/2004	6/30/2004	Complete
2.1b	Commercial Prototype Engineering Design - Caking Coal	8/30/2004		
2.2	Baseline Data Review	4/15/2004	4/15/2004	Complete
2.3a	Commercial Prototype Construction - PRB Coal	4/15/2004	6/15/2004	Complete
2.3b	Commercial Prototype Construction - Caking Coal	9/30/2004		
2.4a	Commercial Prototype Testing - PRB Coal	6/30/2004	8/30/2004	Discontinued
2.4b	Commercial Prototype Testing - Caking Coal	11/30/2004		New Date: 12/15/04
2.5a	Data Processing and Evaluation - PRB Coal	7/30/2004	8/30/2004	Complete
2.5b	Data Processing and Evaluation - Caking Coal	7/31//2004		
2.6	Commercialization Plan Development	--	--	Task Eliminated
2.7	Design and Fabrication of Commercial Burner System	--	--	Task Eliminated
2.8	Task 2 Management and Reporting	9/30/2005		
♦	Final Report	9/30/2005		